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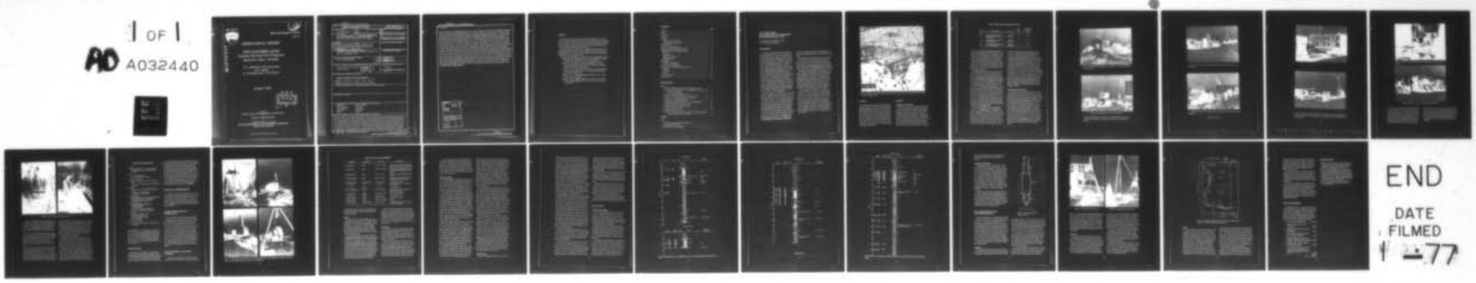

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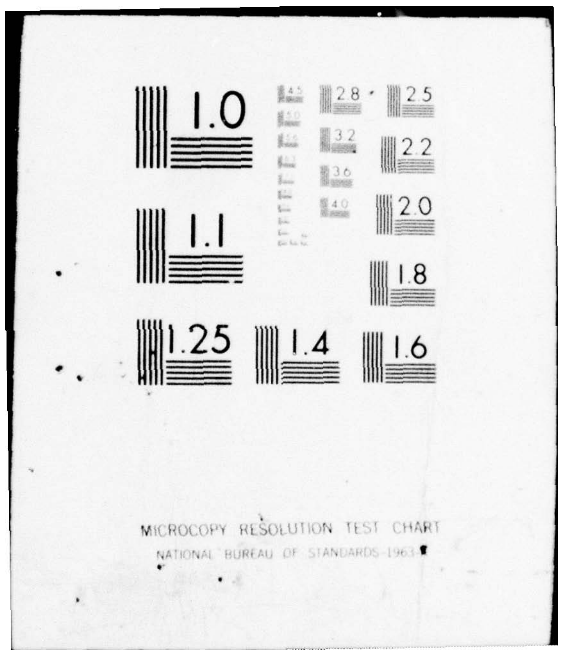
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OPERATIONAL REPORT

1976 USACRREL-USGS Subsea Permafrost Program Beaufort Sea, Alaska

P.V. Sellmann, R.I. Lewellen,
H.T. Ueda,
E. Chamberlain, S.E. Blouin

October 1976

Prepared for
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During the spring of 1976, three holes were drilled offshore in the Prudhoe Bay area using the sea ice cover as a drilling platform. The objectives of this program were to obtain samples and subsurface information to aid in quantification of the engineering characteristics of permafrost beneath the Beaufort Sea as well as to conduct supporting thermal and geological studies. The results of the drilling and related investigations are being used in conjunction with data from other subsea permafrost projects to develop maps and models for the prediction of permafrost occurrence in this offshore environment. The project also provides a means of testing drilling, sampling, and in-situ measurement techniques in an offshore setting where material types and sea ice conditions make acquisition of undisturbed → next page

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samples extremely difficult. This report documents the operational aspects of the spring 1976 field study; subsequent reports will cover the technical and research results. During the mobilization period in March 1976 mobile drilling and housing facilities were assembled at Prudhoe Bay. The drilling equipment was derived from a variety of sources including several Government organizations (NARL, ONR, USGS and CRREL), while the field housing and some logistics support were contracted in the Prudhoe area. An Acker Mountaineer rotary drill rig was utilized in order to evaluate rotary and drive sampling techniques. No sampling or drilling problems were encountered in the upper parts of the sections (5 to 9 m) which in all cases were fine-grained and cohesive. In these materials conventional drive sampling techniques consistently provided the best results. The lower portions of all sections were coarse grained, including sand and gravel. In these intervals drive sampling also afforded the best recovery and least equipment problems. Although preliminary thermal data indicated temperatures below 0°C throughout all the sections, bonded permafrost was not encountered. Thermal data were obtained periodically from the three holes after their completion and until ice conditions in early June no longer permitted site visits. The holes ranged in depth from 34.0 to 52.0 m from the drill collar. An additional study consisted of an evaluation of a probe device for measuring in-situ engineering properties of the subsea sediments. Probe soundings were made at the drill sites and near the ARCO dock. Probe design allowed side friction and point penetration resistance to be measured separately. Temperature data over the depth of the soundings were also obtained. The probe was advanced by using a hydraulic ram or a drop hammer. The results indicate significant correlation between the two penetration techniques and the general material types identified during the drilling operation.

PREFACE

The authors wish to express their appreciation and thanks for the efforts of the U.S. Geological Survey personnel that participated in this project, particularly Dr. Peter Barnes, who aided in coordination and program development as well as helped to launch the field program. We also wish to thank Dr. Jerry Brown for his help in program planning and technical advice.

The National Oceanic and Atmospheric Administration and Bureau of Land Management funding of this effort and the assistance of Dr. Gunter Weller and Mr. David Kennedy of the Outer Continental Shelf Projects Office in planning and logistics are also greatly appreciated.

The project was undertaken in coordination with the following OCS programs:

Research Unit 204: ***Offshore permafrost studies, Beaufort Sea*** – David M. Hopkins and A.H. Lachenbruch, U.S. Geological Survey

Research Unit 205: ***Marine environmental problems in ice-covered Beaufort Sea Shelf and coastal regions*** – Peter Barnes, Erk Reimnitz and David Drake, U.S. Geological Survey

Research Unit 253: ***Offshore permafrost probing, boundary conditions, properties, processes and models*** – T.E. Osterkamp and William D. Harrison, University of Alaska

Research Unit 271: ***Beaufort geophysical permafrost studies*** – James C. Rogers, University of Alaska

Research Unit 407: ***A study of Beaufort Sea coastal erosion, northern Alaska*** – Robert Lewellen, Littleton, Colorado (in process of being completed)

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1976 USACRREL-USGS SUBSEA PERMAFROST PROGRAM, BEAUFORT SEA, ALASKA

P.V. Sellmann, R.I. Lewellen, H.T. Ueda,
E. Chamberlain and S.E. Blouin

INTRODUCTION

The objectives of this program were to quantify the engineering characteristics of permafrost beneath the Beaufort Sea and to determine the relationships among such parameters as sediment type, ice content, and chemical composition. In addition, supporting thermal and geological data were to be acquired. The results of the program are intended for use in conjunction with data from other subsea permafrost projects to develop maps portraying the occurrence and depth of permafrost under the Beaufort Sea. In addition the drilling project will provide subsurface samples and control for other Outer Continental Shelf investigations. It is also designed to test drilling, sampling, and in-situ measurement techniques in an offshore environmental setting where material types and sea ice conditions make acquisition of undisturbed samples extremely difficult. The project was part of the OCS program directed by the National Oceanic and Atmospheric Administration under the sponsorship of the Bureau of Land Management.

During the spring of 1976 (late March to early May) the offshore drilling and sampling program was undertaken in the Prudhoe Bay area, using the sea ice cover as a drilling platform. The field program was jointly conducted by the U.S. Army Cold Regions Research and Engineering Laboratory and the United States Geological Survey (Menlo Park) in cooperation with Office of Naval Research-supported investigations. The drilling sites were selected to cover a range of thermal and geological settings controlled by distance from shore, occurrence of offshore islands and bars, and a range of water depths. The drilling program (Osterkamp and Harrison 1976) and geophysical studies (Rogers 1976) conducted in 1975 by the University of Alaska were helpful in determining site locations and general characteristics of this offshore environment.

Several industry studies have been carried out in this area with emphasis on subsea engineering and permafrost properties, with some of the results available in the public domain. One such study was the 152-m (500-ft) hole drilled by the Humble Oil & Refining Co. on Reindeer Island. The nature of the remaining studies from which data are available will be discussed in future technical reports.

The program was conducted at Prudhoe Bay from 20 March to 8 May, and included 12 days for mobilization and demobilization of equipment. The equipment organized and used for the project was largely provided by CRREL and ONR. The ONR equipment was available from the subsea permafrost program sponsored through the Arctic Institute of North America, under contract N00014-75-C-0635, subcontract ONR-457 to Dr. Robert I. Lewellen (Lewellen 1973, 1976b).

It was originally proposed to have the drilling performed by a contractor; however, the final projected cost proved to be substantially higher than originally estimated. This forced the project to consider the alternative of providing its own drilling support. Not only would the cost be considerably less, planning would be simplified and greater over-all flexibility allowed. In addition this alternative would help the government develop its exploratory drilling capability in this very difficult environment. For these reasons the actual drilling and sampling were undertaken by project personnel.

Figure 1. CRREL-USGS subsea drilling locations, Prudhoe Bay region. (Photograph from NASA, Flight no. 74-101, 27 June 1974.)

LOCATION

The drill sites were jointly selected by USGS and CRREL personnel to provide a range of thermal and depositional settings. All sites were situated within Prudhoe Bay with the exception of the most seaward site, which was located north of the barrier islands (Fig. 1). These sites were accurately positioned in the field by USGS personnel using a Del Norte ranging system which, based on electronic triangulation, can locate stations with 1 meter (3 ft) accuracy. Table I contains site information for the three holes drilled in 1976 (Barnes, pers. comm.).

LOGISTICS

Logistics prior to field study

This program included a considerable logistical effort both prior to the field operation and during the drilling and sampling phase. Except for the drilling equipment at Barrow, all necessary hardware for a self-sustained operation originated at or was shipped to Fairbanks where it was stored at the CRREL field facility for truck shipment to Prudhoe. Items such as drill pipe and casing, purchased on the West Coast, were shipped directly to Fairbanks by the vendor. Other items, such as sampling equipment, the drill rig,

Table I. Drill site locations and general description.

Site	*General location*	*Lat/Long*	*Water depth (m)*	*Hole depth from drill collar (m)*
PB-1	Approximately 2 miles north of old ARCO dock in center of Prudhoe Bay	70°20.9'N 148°19.3'W	2.7	33.8
PB-2	Approximately 2 miles north of Reindeer Island	70°30.7'N 148°18.1'W	11.6	42.8
PB-3	Approximately 3 miles northeast of the new ARCO dock	70°25.9'N 148°26.6'W	5.9	51.5

tools, instrumentation, and hardware originated in Hanover, New Hampshire, and were flown by the Air National Guard to Fairbanks on two military C-130 aircraft. These were scheduled routine training missions from Schenectady, New York, to Fairbanks.

By mid-February all of the equipment had arrived in Fairbanks. Two truckloads of equipment, including some of the OCS sea ice projects hardware, were transported to Prudhoe at the end of February by a local trucking contractor.

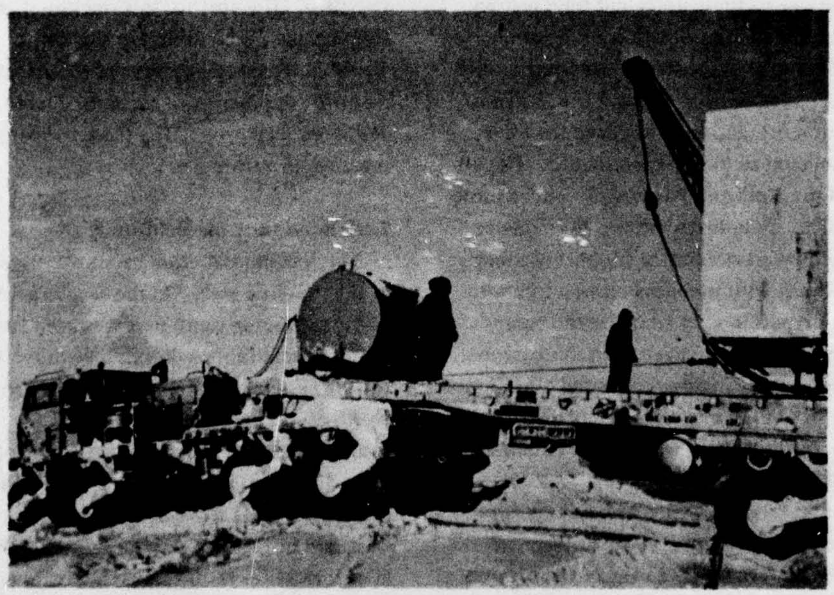
The AINA-ONR drilling equipment from Barrow included a drill sled, shop sled and associated equipment. The large size of these units and time restrictions, which eliminated consideration of the annual shiplift, required that they be transported to Prudhoe by conventional cat train or Rolligon. The availability of equipment, cost, and time involved for a cat train left the Rolligon as the best alternative. The common use of the Rolligon, particularly under snow-covered conditions, by industry on the North Slope has demonstrated its cross-country support capability. Based on discussions with potential contractors who would consider preparing a cat train for the equipment move, a cat train would have been more expensive than the Rolligons. The pounding and vibration associated with sleds drawn by cats would also have caused maintenance problems which were eliminated with the smoother Rolligon ride.

The OCS Arctic Projects Office in Fairbanks arranged for the equipment move. Two Rolligon vehicles were used, a CATCO RD-85 single tractor unit and an RD-85/RDT-45 tractor-trailer unit. The equipment was moved during the first week of March. The distance from Prudhoe to Barrow is approximately 420 kilometers (260 miles). The one-way time for the trip was about the same in both directions – approximately 26 hours each way. The total time for the round trip, including loading and a rest period, was 59.5 hours. The maximum speeds attained were between 29 and 32 km/hr (18 and 20 miles/hr). The lowest rate attained was 5-8 km/hr (3-5 miles/hr) during bad weather when visibility commonly did not exceed 15 m (50 ft). Fuel consumption ranged from 23-38 liters/hr (6-10 gallons/hr). The trip was cross-country on unprepared surfaces and snow trails with less than half the journey over sea ice. The estimated load on the single tractor unit was 9,000-11,000 kg (20-24,000 lb), while the tractor-trailer unit carried a load of 13,600 kg (30,000 lb). Each vehicle was operated by a crew of two men. The cost for this operation as well as other support costs are covered in the cost summary section. Dr. Robert Lewellen prepared the AINA-ONR equipment for shipment and supervised its loading on the Rolligons at Barrow. The loading operation at Barrow is shown in Figure 2.

Logistics during the field study

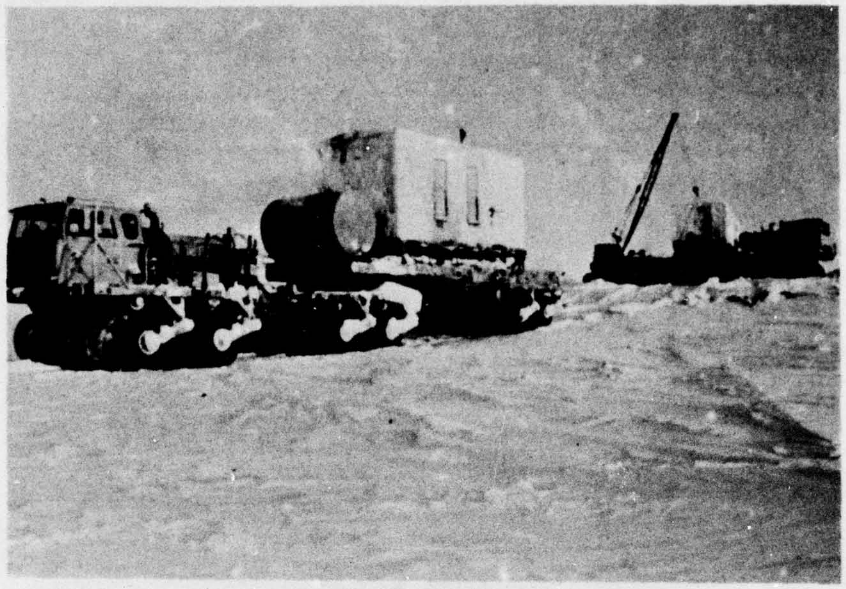
The V-E construction camp was used as a base camp in the Prudhoe area. On the sea ice a 4.9-×4.9-m (16-×16-ft) eight-man camp unit was used for living and cooking accommodations during the study. CRREL arranged for the lease of the field camp from Crowley Maritime North Slope Rolligon group (CATCO). The unit is normally installed and transported on a Rolligon tractor bed. The camp is a complete facility with a gas-incinerator toilet, gas stove and oven, electric refrigerator, sink, and hot and cold running water. Water was stored in an 1135-liter (300-gallon) tank and was heated by a gas-fired unit. Water consumption averaged around 11 liters/day (3 gallons/day) per man. Power was provided by an 18-kw diesel-powered generator set. The camp, generator, 3785-liter (1000-gallon) fuel tank, and soils lab building were installed on a 12.2-m (40-ft) sled (Fig. 3).

a. Snow ramp and tractor being used to load drill sled on the RD-85/RDT-45 tractor-trailer unit.

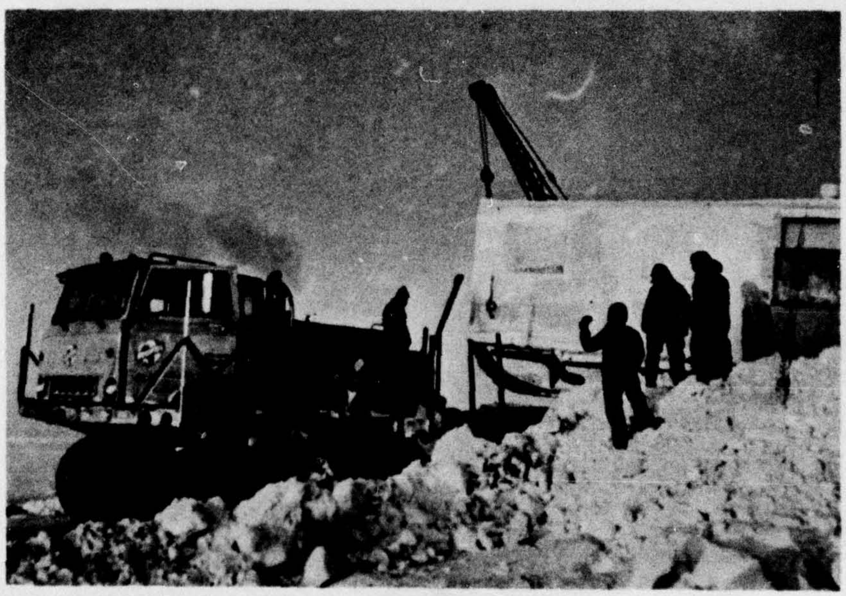


b. Final positioning of drill sled on the tractor-trailer.

Figure 2. Rolligon RD-85 single tractor and RD-85/RDT-45 tractor-trailer unit being loaded at Barrow. (Photographs taken by Leslie Nakashima of NARL.)



c. Loaded tractor-trailer, with RD-85 single trailer in background being loaded with the shop sled.



d. The shop sled loaded on the single tractor was carried normal to the vehicle's long dimension.

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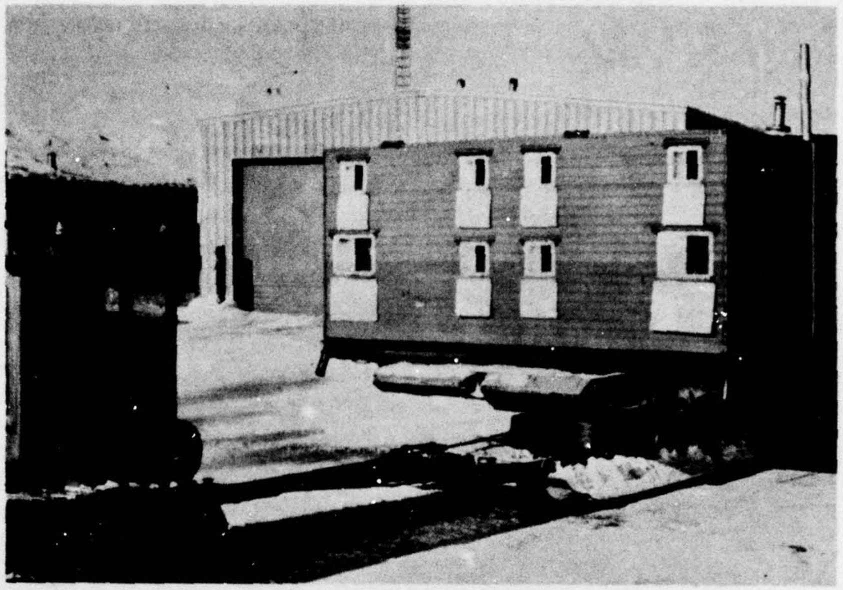

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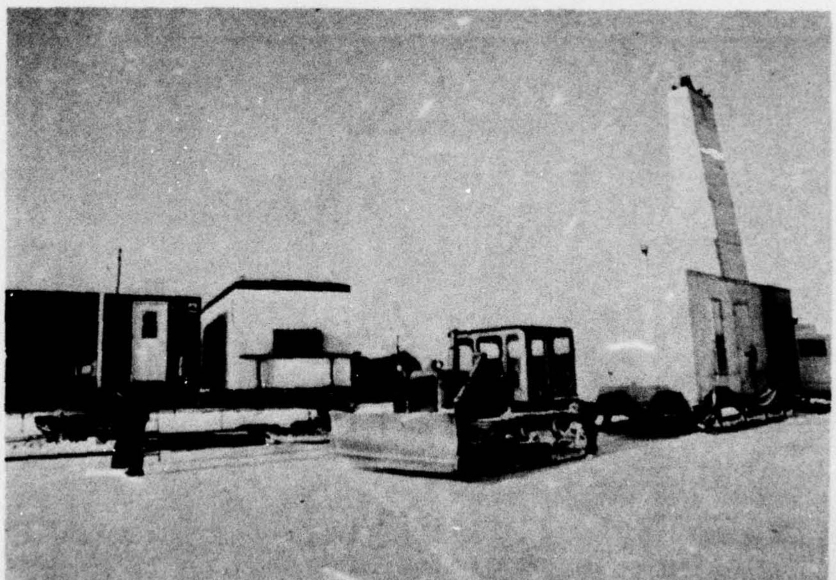

b.

***Figure 3.** Camp unit mounted on large 12.2-m (40-ft) sled. Lower photograph shows all of the equipment on the camp sled, as well as the drill and shop units being towed by the D-6 cat.*

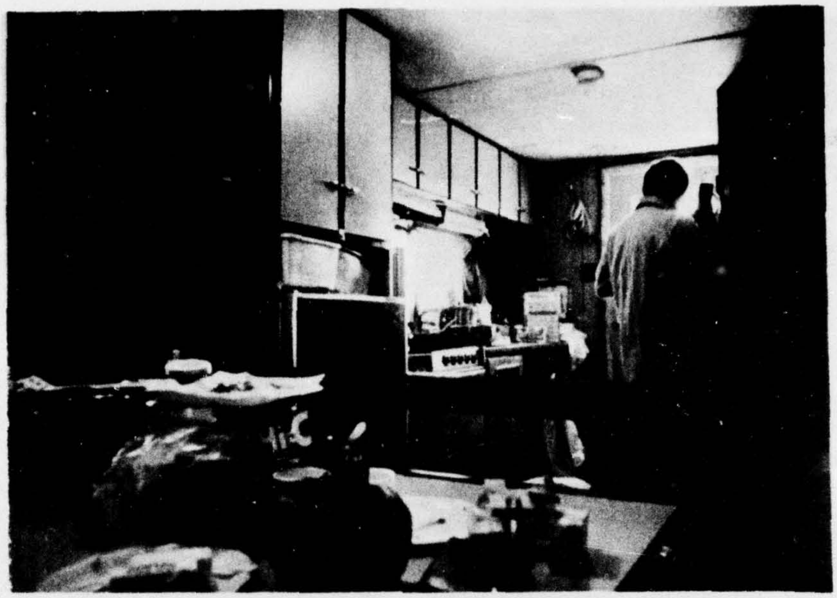

Figure 4. Interior of field camp showing kitchen and eating area; bunk rooms are to the right.

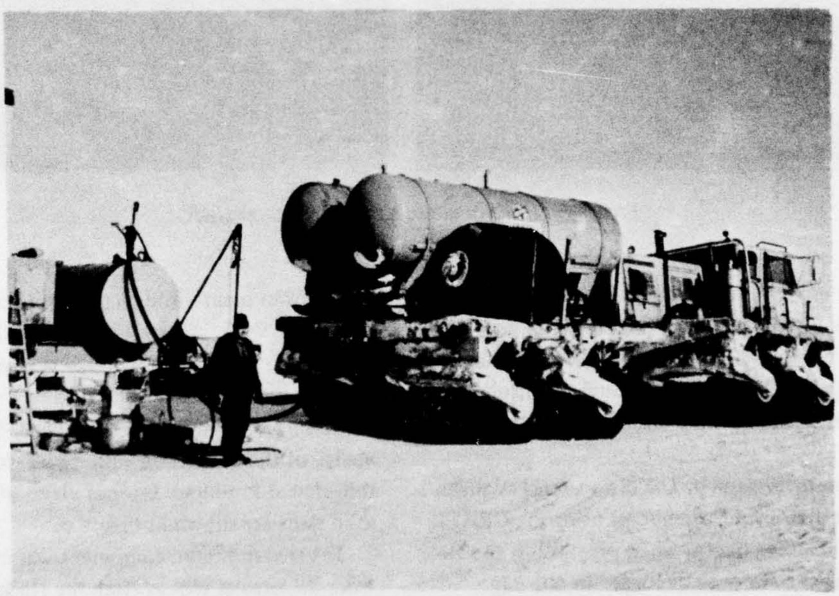

Figure 5. Rolligon tractor shown filling the camp fuel tank.

The camp unit, although crowded, accommodated eight men satisfactorily. The only problems experienced were with the gas toilet, and with the gas-fired part of the heating system. Camp heat was provided with both electricity and propane gas. The two 1.5-kw electric heaters were capable of heating the unit when temperatures were above -26°C (-15°F) and wind velocity remained low. When the gas heaters were required one of the two heaters always performed well. The heater on the windward side normally stopped cycling, apparently because of draft problems with the side-wall mounted vents. Other than these minor problems the camper and associated facilities worked extremely well. The interior of the housing unit is shown in Figure 4.

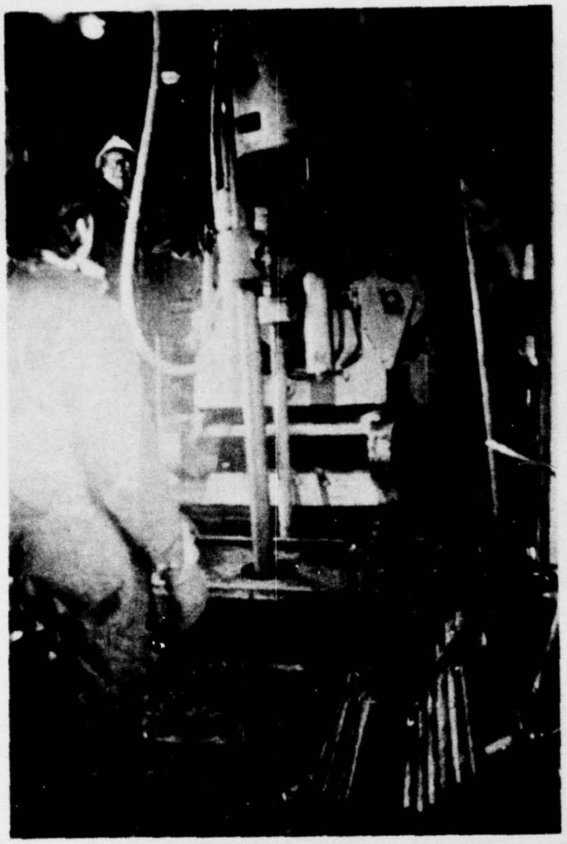


Figure 6. Interior views of drill and shop sleds.

Resupply of food, fuel and water and transport of personnel back to Prudhoe for occasional laundry and shower runs were usually provided by Rolligon transport (Fig. 5). The NOAA helicopter also delivered some supplies and mail and provided personnel transport.

The sites were revisited by USGS personnel (Vaughn Marshall) for thermal measurements using the CRREL-supplied Bombardier tractor when practical or the Rolligon when all sites were to be logged in one day. Helicopter support was required to revisit the sites during early June because of deteriorating ice conditions.

All the project drilling equipment was sled-mounted to permit movement over the sea ice. Two sleds (Panitchek type) from NARL with a 6.1-x 3.7-m (20-x12-ft) deck space were used for this purpose. A work shop outfitted for making equipment repairs and housing spare parts and sampling gear was permanently mounted on one of the sleds. In addition, it housed an auxiliary 3-kw power plant. The second sled housed the drilling rig, pump, water storage tank and mud pit. Free floor space in both sleds was used for storage and transport of drill pipe and casing. A specially designed, inclosed, 9.1-m (30-ft) derrick which matched the hoisting capability of the new Acker drill rig was installed on the drill sled at Prudhoe. Interior views of the drill and shop sleds are shown in Figure 6.

The sled-mounted equipment was moved to and from the sites as well as from the staging area at the V-E Construction Camp with a D-6 Caterpillar tractor. This tractor was leased from V-E Construction by the OCS Arctic Project Office. All of the sleds could not be pulled at once during normal operations on the sea ice. The large sled with the housing unit was moved by itself. The two smaller shop and drill sleds were coupled together and moved as a single unit. Movement of the sled units over the smooth Prudhoe Bay ice presented no problem with speeds of approximately 5 km/hr (3 miles/hr) common. The only difficulty was encountered

Table II. General equipment list.

1. *Vehicles*
   - Bombardier Muskeg tractor and trailer (CRREL)
   - D-6 Caterpillar tractor (V-E Construction, OCS contract)
2. *Sleds*
   - 2 pipe sleds (ONR-NARL)
   - 1 runner sled (Nabors – OCS contract)
3. *Housing accommodations*
   - 16-ft × 16-ft 8-man camp unit (CATCO-CRREL contract)
   - 10-ft × 20-ft soils lab and storage unit (CATCO-CRREL contract)
4. *Generators*
   - 18-kw generator unit (diesel) (CATCO-CRREL contract)
   - 3-kw generator unit (diesel) (ONR)
   - 1.5-kw generator unit (gas) ONR)
5. *Drilling equipment*
   - Acker Mountaineer drill unit (gas-powered) (CRREL)
   - Bean pump (diesel-powered) (AINA-ONR)
   - Storage tanks and mud pit (AINA-ONR)
6. *Sampling equipment*
   - Two wire line strings (CRREL-OCS)
   - NX casing (ONR-OCS)
   - New drill rod (OCS)
   - Rotary double wall barrels (ONR-OCS)
   - Range of drive sampling barrels (ONR-OCS)
7. *Shop facilities*
   - Hand tools (mechanic set) (OCS)
   - Bench grinder (CRREL)
   - Shop air compressor (CRREL)
   - Electric drill (OCS)
8. *Probe equipment* (CRREL)

Note: When OCS is indicated items were purchased from project funds.

when attempting to move the sleds over gravel roadways such as the road around the bridge construction activity on the Sagavanirktok River. At this location the units had to be moved separately by winching them in short 9- to 15-m (30- to 50-ft) increments. Table II contains a list of all the equipment used during the operation.

COMMUNICATIONS

Several radios were available for communication between the drill sites, Prudhoe, and Barrow. The OCS program provided a single side-band unit for this purpose. This unit, made by Spillsbury and Tindall, was very reliable and compact. The most useful radio was provided by CATCO, and was installed in the eight-man housing unit. This unit operated on their exclusive frequency and was monitored 24 hours a day at the CATCO operations facility. The CATCO radio system is normally used for supporting Prudhoe area Rolligon operations. This radio support was comparable to telephone service and provided an excellent means of handling all necessary contacts with Prudhoe including support requests for resupply of the camp. The excellence of this communication support was largely due to the cooperative spirit of the CATCO personnel who were also always willing to serve as project **expeditors.**

PERSONNEL AND RESPONSIBILITIES

The number of personnel involved in this project during the field study totaled 13, although not all the individuals were in the field at the same time. The size of the permanent crew varied between 7 and 9. The individuals that participated in the study, their general areas of responsibility, and time period in the field are indicated in Table III.

EQUIPMENT MOBILIZATION AND DEMOBILIZATION

The period from 21-30 March was spent preparing the equipment for the field program. Prior to sorting and organizing all the equipment shipped to Prudhoe by truck it was necessary to excavate it from snow drifts. The shop and drill sled were first unpacked and reorganized. The drill sled was completely stripped of equipment to facilitate installation of the new Acker drill rig and enclosed tower prefabricated at CRREL in Hanover, N.H. The use of this new drilling rig and mast required reorganization of available space on the drill sled as well as construction of an elevated base for the drill. Sampling tools, drill rod and casing were also sorted and prepared for the operation. Photographs of the various phases of this work are shown in Figure 7.

DRILLING EQUIPMENT AND SAMPLING TECHNIQUES

A general list of equipment used by this project is provided in Table II. This section contains a discussion

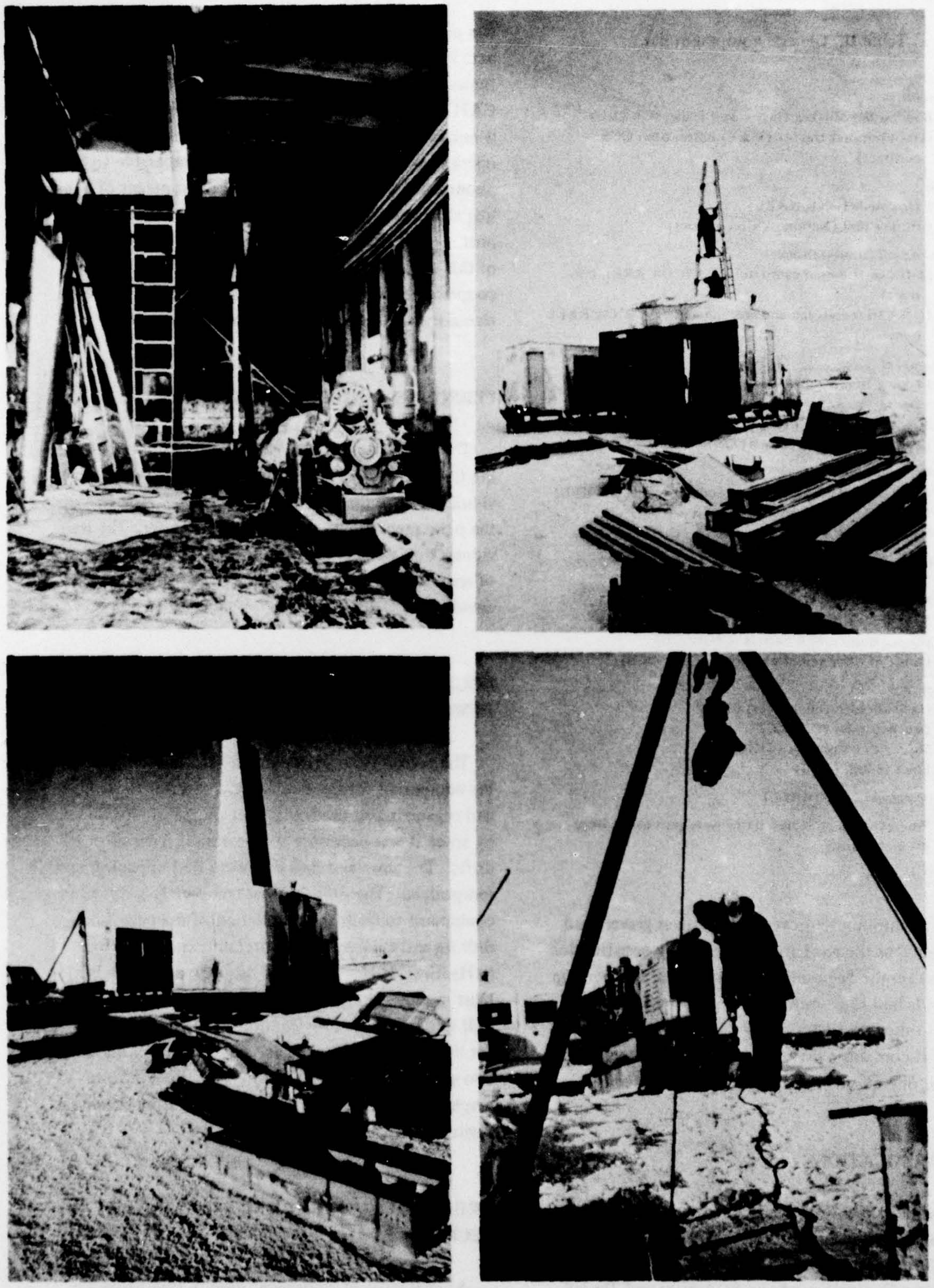

Figure 7. Drill sled being modified with new tower and drilling unit. In lower right the new Acker unit is being loaded on the Bombardier trailer for transfer onto the drill sled.

Table III. Field party and responsibilities.

Individual	*Organization*	*Time period*	*Responsibility*
Dr. Peter Barnes	USGS	21 March to 7 April	Positioning of sites, aid in mobilization, sedimentary processes (RU 205 and 204).
Mr. Dave Carter	USGS	30 March to 15 April	Hole and core logging (geological studies, RU 204) shared responsibility with D.M. Hopkins.
Dr. David Hopkins	USGS	14 April to 3 May	Hole and core logging (geological studies; RU 204).
Mr. Vaughn Marshall	USGS	29 March to 8 May	Thermal logging of holes (RU 204) and independent thermal probe studies.
Dr. Robert Lewellen	Arctic consultant	31 March to 8 May	Drilling and thermal data.
Mr. Scott Blouin	CRREL	7 to 28 April	Engineering problems of materials and probe program.
Dr. Jerry Brown	CRREL	1 and 2 April	Core chemistry study.
Mr. Edwin Chamberlain	CRREL	29 March to 6 May	Engineering properties of materials, core logging and probe program.
Mr. Allan Delaney	CRREL	20 March to 7 April	Mobilization and drilling.
Dr. I.K. Iskandar	CRREL	1 and 2 April	Core chemistry study.
Mr. Paul V. Sellmann	CRREL	20 March to 6 May	Drilling and core logging.
Mr. Herbert Ueda	CRREL	20 March to 16 April	Drilling.
Mr. Edwin Hindman	Contracted OCS	9 March to 1 May	Equipment operator from V-E Construction (tractor operator).

of the drill equipment, as well as an evaluation of performance including comments on both drilling and sampling techniques.

Drill unit

The Acker drill provided by CRREL is powered by a 48-hp gasoline engine and has the capability of handling 88-mm (3½-in.) O.D. NX casing directly through the spindle. The rig is rated at a 610-m (2000-ft) depth capability using NW rod, which is primarily based on the drill rig's hoisting capability. The unit was fitted with both a hoist for wire line coring operations and a cathead hoist.

The drill unit operated well; it started easily and was mechanically trouble-free. The only problems were restricted to the hydraulic system. The system initially required considerable attention to stop all leaks. Leaks in the slave cylinder of both the clutch and brake for the wire drum hoist could not be stopped and consequently the cylinder required continual replenishment of fluid. The major problem was associated with the wire line hoist: the drum would not hold when lowering a load. This was the only equipment problem not resolved in the field. A mechanical brake would have been an ideal addition to this hoist.

The mast performed well, allowed considerable flexibility and was well matched to the rig's hoisting capability, as was demonstrated on several occasions while pulling casing under extremely difficult hoisting conditions. The only necessary field modification was installation of a cathead rope stabilizer which prevented the rope from jumping off the rear sheave in the crown block.

Pump station

The circulation pump used was a Bean horizontal triplex pump that was rated at 95 liters/min (25 gal./min) at 4.8 MN/m^2 (700 psi). It was powered by a 2-cylinder Deutz air-cooled diesel engine. This pump was part of the AINA-ONR equipment transported to Prudhoe from Barrow.

The pump was installed in the drill sled with the remainder of the drilling equipment. Water for drilling purposes could be drawn from several locations: the storage tanks (1900 liters; 500 gallons), mud pit, or directly from below the sea ice. This unit worked extremely well; it started with no difficulty and operated maintenance-free during the entire period at what appeared to be extremely low fuel consumption rates.

The only difficulty encountered with the unit occurred during operation with viscous drilling mud. There were no provisions for removing sands from the drilling mud, and drilling in the abundant fine sandy formations for even a short period caused the mud to become sand-saturated which prevented proper pump valve operation. For this reason drilling mud was only used on this one occasion.

Drilling and sampling

The drilling techniques used were governed by the program requirements for undisturbed samples at frequent intervals. Attempts were made to sample the upper, fine-grained part of the section (5 to 9 m; 16 to 30 ft) on a continuous basis. Sampling below this depth in the sands and gravels was done at greater intervals as controlled by casing placement procedures.

The unstable nature of the sediments required that the holes be cased over their entire depth. Casing was set by two techniques, driving and rotary drilling. The most practical and effective approach for the penetration required was the drive technique. The approach used to assure maximum penetration was to predrill in advance of the casing. The procedure for advancing hole involved 1) predrilling several inches short of the depth of the next anticipated sample depth, 2) driving casing to that depth, 3) cleaning out the casing to within 2 to 8 cm (1 to 3 in.) of the bottom of the casing shoe, and 4) returning down the hole for a sample run into undisturbed material. This procedure was then repeated to the next depth.

Most of the samples obtained during the study were taken by drive sampling techniques. Two types of drive samplers were used with considerable success. In the fine-grained material (clay silts and sandy silt) the Diamond Drill Contracting Company (DDC) Washington sampler was an ideal tool. It provided excellent core recovery and relatively undisturbed samples 5 cm (2 in.) in diameter. There was no requirement for a core-retaining device with this sampler due to the design of the shoe. The sampler had a solid barrel and core was removed using a hydraulic sample extractor. Maximum sample length was 61 cm (24 in.).

Coarse-grained material was sampled with a Lynac drive sampler. This sampler has a split-tube barrel and has provisions for using a core catcher or basket and obtaining a 46-cm (18-in.) core, 5 cm (2 in.) in diameter. The Lynac heavy barrel construction made it well suited for use in the dense sands and gravels. Retaining these usually cohesionless materials in any type of sampler is a common problem. All available standard sample retainers were employed with no consistent or general success. After modification of the retainer and use of flexible sample sleeves cores were obtained on every run with a high percentage of recovery. The core catcher used was a simple four-spring retainer which fitted loosely in the retainer recess ring in the barrel. A thin-walled rubber sleeve was attached to the retainer and extended up into the barrel. The sample passing into the sleeve caused it to extend and apply a confining force on the sample at the same time. This kept the sample intact and confined in the barrel.

Potential chemical contamination of the samples obtained with these drive samplers should be extremely low. Both samplers had ball check valves in the upper ends of the core barrels, eliminating the chance for sea water in the hole to enter the upper end of the sampler. The Washington sampler had a tight ball check valve that sealed extremely well. Therefore, the only source of contamination came from the bottom of the sample. This was not considered a serious source of contamination because of the short transit time while returning to the surface and limited chance of infiltration. To further reduce the chance of contamination through infiltration only fine-grained material was selected for chemical analyses.

Rotary sampling techniques using conventional double-wall core barrels as well as drive samplers were used in the coarse-grained section. The rotary barrel equipped with tungsten carbide cutters was used to obtain core. There were problems associated with bit wear and movement of the barrel through the casing because of the coarse sands and gravels. Small gravel, cuttings and fine sand continually wedged between the upper shoulder of the barrel and the casing, particularly if the entire barrel was advanced beyond the end of the casing. Because of these problems, drive sampling was used exclusively in the last hole drilled.

Wash samples were collected during the casing cleaning and predrilling operations, usually at 0.6-m (2-ft) intervals. They were collected directly at the top of the casing or from the pipe leading from the surface discharge "T" to the mud pit, depending on the drilling configuration at the time.

Drilling problems

Sampling and drilling in the upper part of the fine-

grained marine section presented few problems. This can be attributed to the lack of gravel and the cohesive nature of this material. The coarser grained alluvial part of the section caused the greatest difficulty. Problems were related to the unstable nature of the sands and gravels which required the hole to be cased over its entire length. Casing placement was difficult in parts of the sections due to high penetration resistance. In holes PB-2 and PB-3, bottom depth was limited by the depth to which casing could be placed. In PB-2 casing was unsupported in the water column for more than 12 m (40 ft), limiting the amount of driving energy that could be transferred down the string. At this site, the casing was advanced to refusal. In PB-3 depth was also limited by the depth of casing installation. The lower joint of casing failed in this hole, preventing further driving. The casing employed was the most heavy duty, flush joint NX casing available and designed for driving in glacial till.

In two situations, at the bottoms of boreholes PB-1 and PB-3, tool problems and time constraints dictated the total hole depth. In PB-1, the rod twisted off in the tool joint at a point 3 m (10 ft) above a double-wall core barrel. The break occurred at 29 m (95 ft) below the hole collar. When an attempt was made to core just below the casing shoe, flowing sands and small gravel moved into the annulus between the barrel and casing, thus causing an increase in torque, and lodging and subsequent failure of the joint. The casing was cut off just above the rod break, the PVC tubing installed, and the casing pulled. After the casing was pulled it was discovered that the casing cutter had not cut through the casing wall, but had unthreaded the first joint above the intended cutting point. The entire casing string and barrel could have been recovered if time had permitted.

In the second case, metal cuttings from the 49-m (162-ft) depth indicated problems. The casing threads had failed in the casing shoe due to hard driving conditions. The casing was cut above the problem depth, the PVC casing installed for thermal measurements, and the NX casing pulled.

The sands common to the alluvial section also can cause problems if drilling procedures are not planned with this material in mind. When drilling in advance of the casing the sands would flow and backfill the casing as much as 4.6 m (15 ft) after the drill string had been retracted. To assure an undisturbed hole bottom for sampling purposes it was possible to prevent return of the sand by stopping the cleanout run several centimeters above the bottom of the casing shoe, and slowly extracting the drill rod to prevent a piston effect. This left a plug of compacted material formed during casing setting at the end of the shoe. Once this plug was penetrated, sands would normally flow up into the casing.

Another common problem related to the sand and gravel sections was the loss of circulation after drilling ahead of the casing shoe. In the coarse-grained material it was seldom possible to advance more than 1.5 m (5 ft) ahead of the casing without losing circulation.

Another problem related to the coarse-grained material in the lower part of the section was the wear on bits, rod and casing. The drill rod and casing received more wear than the bits since material disaggregated by the bit would pass up the hole and be further crushed between the pipe and casing.

A detailed discussion of all drilling and sampling procedures and associated problems may be found in the formalized drillers' field notes (Lewellen 1976a).

HOLE LOGGING

Descriptive field logging

The holes were logged at the time of drilling to provide a complete description of the materials encountered. These logs were based on 1) cores, 2) wash samples, and 3) drillers' observations of penetration characteristics. Preliminary logs of these holes were prepared by David Hopkins and David Carter of the USGS and are shown in Figure 8.

Subsampling of the core was also completed in the field. Cores were split for detailed examination of engineering properties, chemical analysis, dating and paleontological examination. The cores were subsequently boxed and transported to one of two locations, CRREL in Hanover or the USGS office in Menlo Park.

Even though permafrost appears to exist (based on the thermal data) throughout the entire interval in all holes, there was no evidence of bonded permafrost with the possible exception of the base of PB-2. This possibility was based on the fact that in this zone, circulation was maintained and refusal was met in attempting to advance the casing. Unfortunately, it was not possible to obtain a sample from this zone.

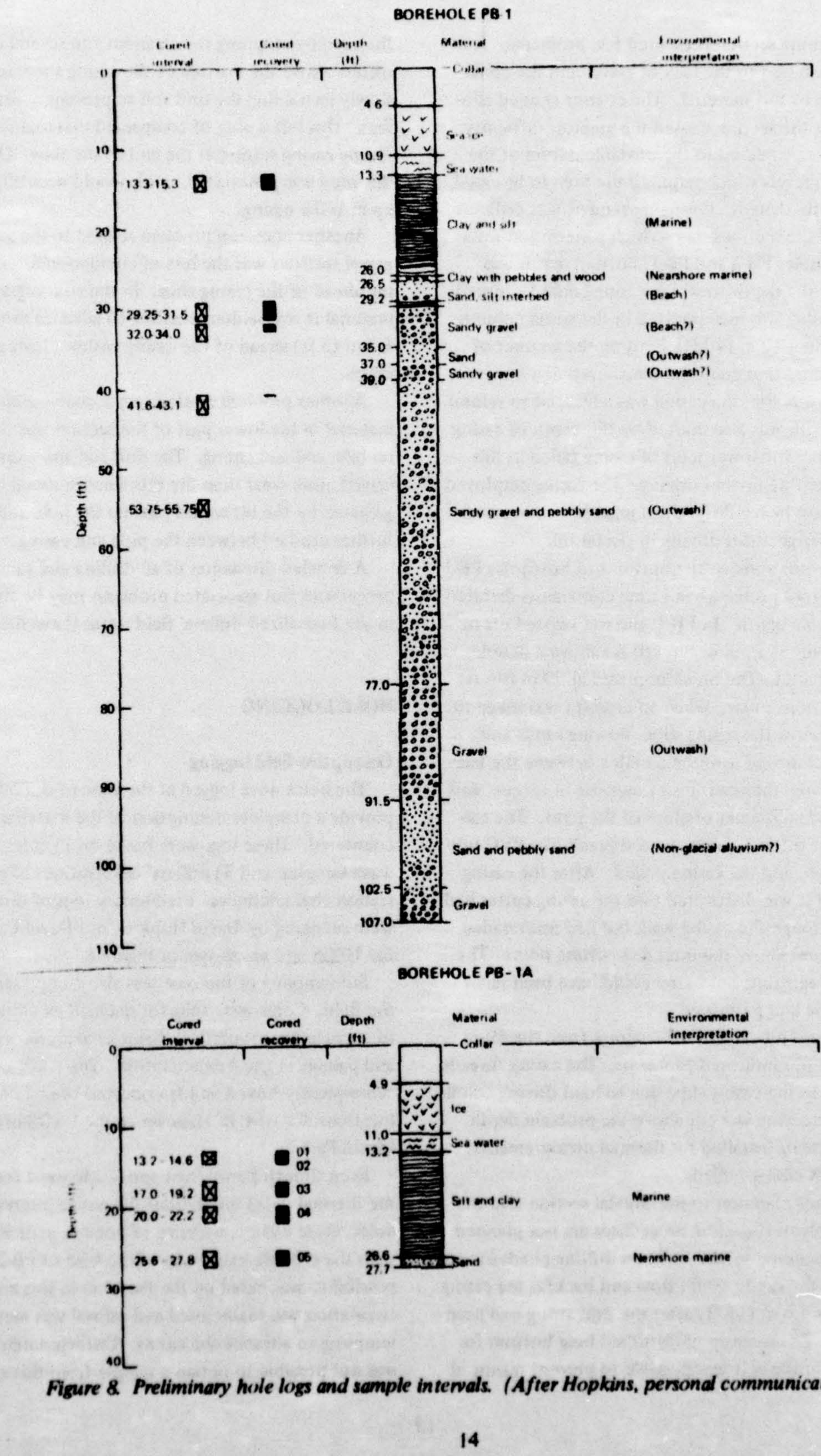

Figure 8. Preliminary hole logs and sample intervals. (After Hopkins, personal communication.)

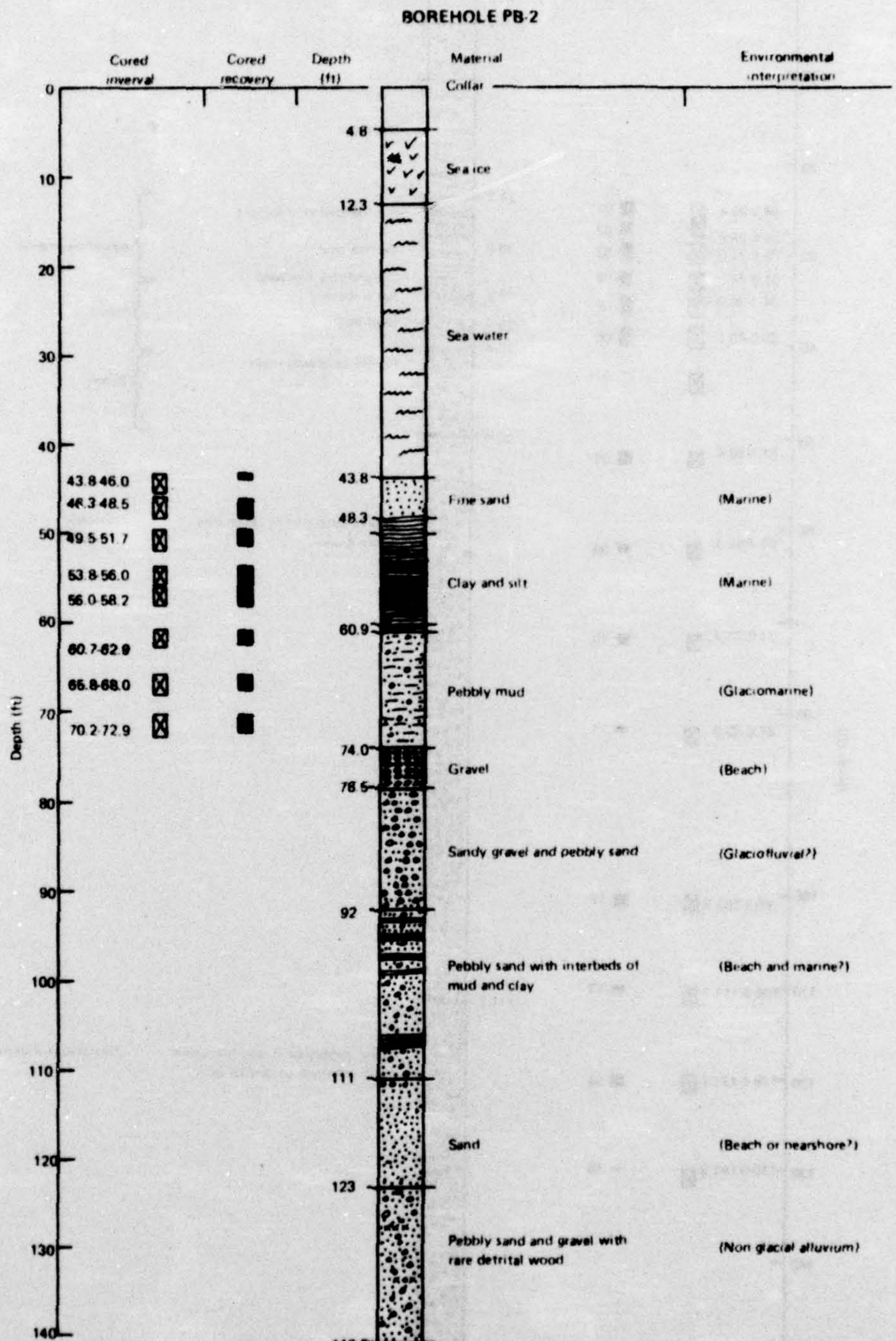

Figure 8 (cont'd).

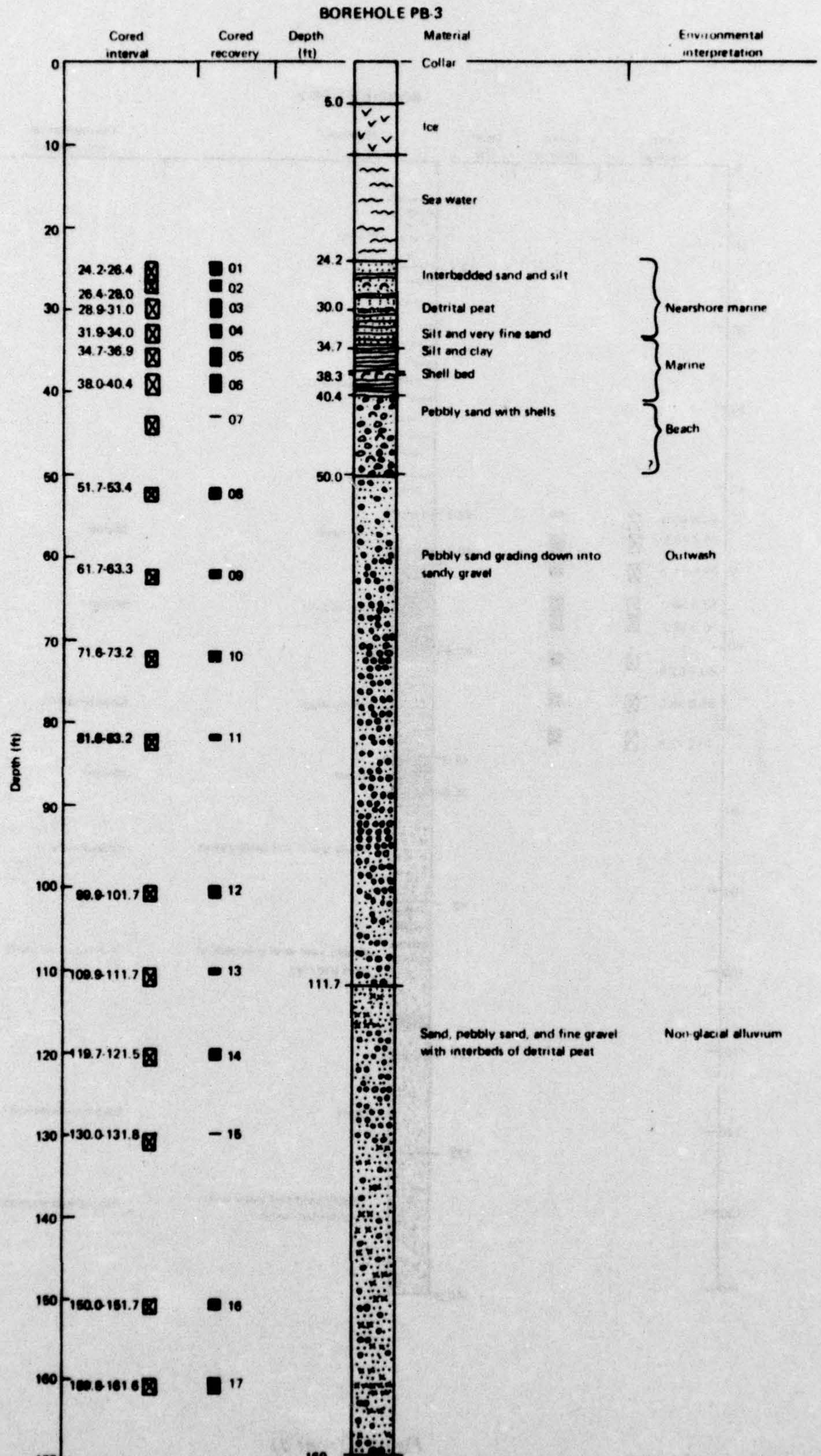

Figure 8 (cont'd). Preliminary hole logs and sample intervals. (After Hopkins, personal communication.)

Only future interpretation of the temperature and chemical data from this section will answer this question.

Temperature measurements

On completion of a hole, a plastic (PVC) casing was installed for thermal logging purposes. The pipe used was 5-cm (2-in.) PVC pipe in 6-m (20-ft) lengths. A 3-m (10-ft) section of iron pipe was installed on the bottom to provide additional weight during installation. Each pipe section was inserted in the hole while the NX casing was still in place. The PVC joints were glued as they were emplaced and then filled with a non-freezing fluid to reduce bouyancy. When the entire PVC casing was installed the conventional NX casing was pulled. In no instance was the PVC casing withdrawn or damaged by the NX casing pulling operation.

Temperature measurements were made at these sites by the USGS personnel (Vaughn Marshall) using a thermistor probe. Temperature profiles were obtained after the installation of the PVC casing and on several occasions after the initial logging. Sites were revisited as late as early June in an attempt to establish equilibrium profiles for each hole. Results of this study will be covered in USGS reports.

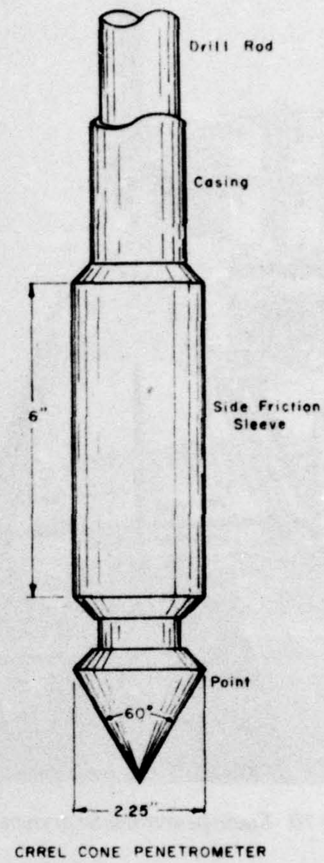

Figure 9. Drawing of probe unit used in the study.

FIELD ACQUISITION OF SEABED ENGINEERING PROPERTIES

Devices for measuring in-situ engineering properties of the subsea sediments were evaluated during the 1976 field season. The principal long-range benefit from this evaluation is the development of a method for acquiring engineering data more rapidly and economically than by drilling. Probe soundings were made adjacent to all the drill sites as well as at a site near the new ARCO dock (North dock). In selecting a probe, it was desired to obtain a maximum amount of data over a wide range of soil types while maintaining simplicity and ease of operation under Arctic sea ice conditions. The cone penetrometer was chosen because it appeared to offer the best combination of versatility, simplicity and data production.

Equipment

The cone penetrometer equipment was fabricated in the CRREL shop using some commercially available components. A loading apparatus was also constructed. The shoulder diameter of the probe is 5.7 cm (2.25 in.) and the apex angle of the cone is 60 degrees. The cone was mounted on EW drill rod, which was inside EX casing. This minimized side friction and allowed the measurement of point penetration resistance alone. The lower 15 cm (6 in.) of the casing also had a diameter of 5.7 (2.25 in.) so that the side friction alone could be measured (Fig. 9). Point penetration resistance and side friction could be obtained separately by successively advancing the point and then the casing. One and a half meter (5-ft) lengths of rod and casing were used as basic driving components, but operation procedures also required the use of a 0.3-m (1-ft) and two 0.6-m (2-ft) sections.

The probe was advanced by two methods: 1) pushing at a constant rate with a hydraulic ram, and 2) impacting with a drop hammer. The constant rate hydraulic or static penetrometer system is shown in

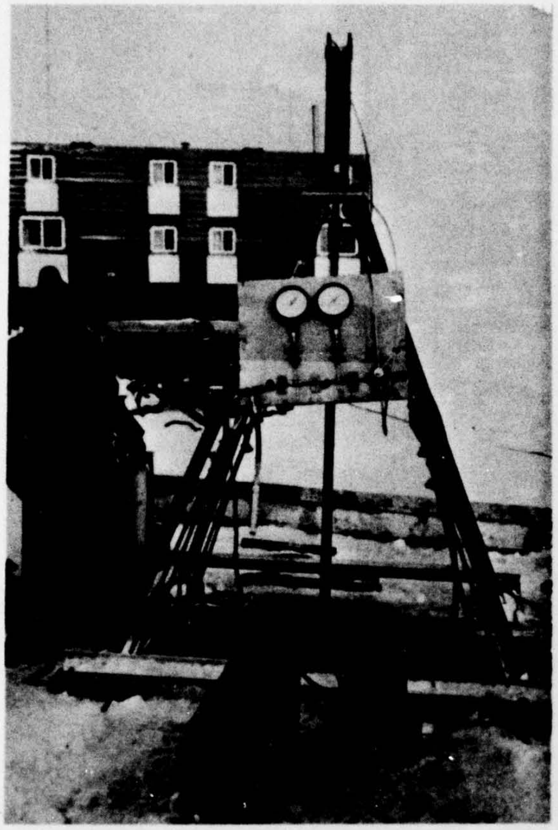

Figure 10. Static penetrometer system.

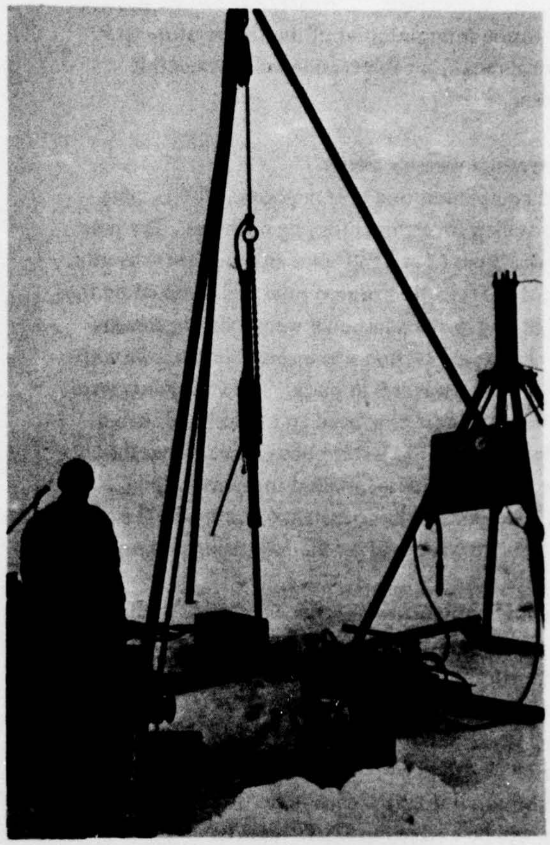

Figure 11. Impact penetrometer system.

Figure 10. Anchors placed in holes drilled through the ice provided the reaction force (approximately 5450 kg; 12,000 lb). The ram was operated by an electrically powered hydraulic pump. A hand-operated pump was also available for supplementary use. The impact penetrometer set-up is shown in Figure 11. A 64-kg (140-lb) tripod-mounted drop hammer driven with a gasoline engine operated cathead was used to drive the penetrometer.

Procedures

To conduct the static penetration test, four holes were drilled through the ice for placing the reaction anchors. A fifth hole was drilled for the penetrometer. The penetrometer was placed in the hole and lowered to the sea floor, sections of rod and casing being added as necessary. When the penetrometer contacted the sea floor, connections were made to the hydraulic ram and loading commenced. The normal procedure was to push the point for 0.3 m (1 ft), recording the ram pressure at 7.6-cm (3-in.) intervals. The ram was then retracted, 0.3 m (1 ft) of casing was added and then advanced 0.3 m (1 ft) with the ram. The ram pressure was again recorded at 7.6-cm (3-in.) intervals. This process was repeated until penetration was terminated, in all cases because of buckling of the double-walled load column. It took about 20 minutes for each 0.3-m (1-ft) cycle with this prototype apparatus.

The impact cone was also driven in 0.3-m (1-ft) increments with separate determinations of point and side resistance. The number of blows required to drive 15 cm (6 in.) was recorded. The 64-kg (140-lb) hammer was dropped 76 cm (30 in.) at approximately 20 blows per minute.

In addition to the penetration resistance, the temperature profile was determined by filling the bore of the rod with a non-freezing fluid and inserting a thermistor temperature probe. Normally, the temperature in the drill rod fluid was allowed to stabilize 12 hours before readings were taken.

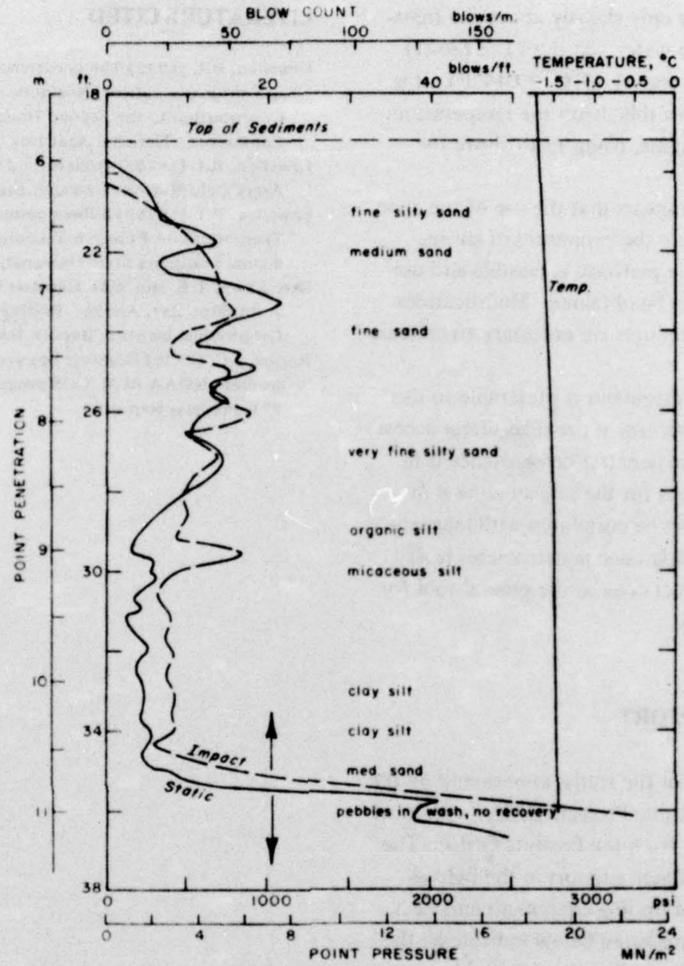

Figure 12. Typical test results obtained with static and impact probe systems, including temperature data with depth.

Results

Figure 12 illustrates some typical test results for the cone penetrometer tests. The data were obtained at site PB-3. The depth from the ice surface to the top of sediment was approximately 5.9 m (19.2 ft). Blow count per foot of penetration for the impact cone and the point pressure for the static cone are plotted as a function of depth. A strong correlation between the two methods can be seen with both reflecting the lithology observed for the drill hole. For instance, initially the blow count and the point pressure both increased as the sand became coarser and decreased as finer fractions were encountered to a depth of 9.1 m (30 ft). Between 9.1 m and 10.4 m (34 ft), both types of data remained constant and at their lowest values as soft clayey silt was encountered. At approximately 10.7 m (35 ft) there was a sharp increase in both the blow count and point pressure as sand and gravel were encountered. Penetration was terminated at this depth in both cases because of the high penetration resistance. In the case of the static cone the rod began to buckle, and in the case of the impact cone the coupling of the drop hammer device to the rod continued to loosen, causing damage to the threaded connection.

The temperature profile at site PB-3 is also shown in Figure 12. The profile is very steep, with a slight warming to the 11-m (36-ft) depth. The lowest temperature observed was -1.69°C (28.96°F) at the top of

the sediments, which is only slightly above the freezing point of normal sea water. At the 11-m (36-ft) depth the temperature was -1.42°C (29.44°F). It is hypothesized that below this depth the temperature might continue to decrease, rising again above the base of the permafrost.

From this study it appears that the use of the cone penetrometer to measure the properties of subsea sediments from a sea ice platform is feasible and useful engineering data can be obtained. Modifications to equipment and procedures are necessary to increase productivity.

The static cone penetrometer is preferable to the impact penetrometer because it provides direct access to engineering data (the penetration resistance is in pressure units, while that for the impact cone is in blow counts which must be correlated with laboratory strength data). The static cone penetrometer is also now replacing the impact cone as the general tool for foundation exploration.

COST OF FIELD SUPPORT

The logistics costs for the study were shared by the project and the OCS Arctic Projects Office, with most of the support coming from the Projects Office. The major cost was for Rolligon support in the field as well as the transport of drilling equipment and sleds from Barrow. The items listed below indicate all the areas in which major expenditures were made.

1. Rental of sled for housing unit	$ 8,250
2. Rental of crawler tractor from V-E Construction	18,890
3. Equipment operator for V-E tractor/ field assistant	11,310
4. Field camp, including soils lab, generator, radio and fuel tank	7,080
5. Rolligon transport from Barrow to Prudhoe of drilling sleds and equipment	28,340
6. Rolligon support in field, including fuel and water resupply	16,060
7. V-E Construction base camp costs including fuel, room and board, labor, storage, NOAA helicopter, and other items	15,000
Total	$104,930

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